DISCUSSION PAPER

January 2013 ■ RFF DP 13-02

Bridging the Energy Efficiency Gap

Insights for Policy from Economic Theory and Empirical Analysis

Kenneth Gillingham and Karen Palmer

1616 P St. NW
Washington, DC 20036
202-328-5000 www.rff.org

RESOURCES FOR THE FUTURE

Bridging the Energy Efficiency Gap: Insights for Policy from Economic Theory and Empirical Analysis

Kenneth Gillingham and Karen Palmer

Abstract

The failure of consumers to make seemingly cost-effective investments in energy efficiency is commonly referred to as the energy efficiency gap. We review the most recent literature relevant to the energy efficiency gap and in particular discuss what the latest insights from behavioral economics might mean for the gap. We find that engineering studies may overestimate the size of the gap by failing to account for all costs and neglecting particular types of economic behavior. Nonetheless, empirical evidence suggests that market failures such as asymmetric information and agency problems affect efficiency decisions and contribute to the gap. Behavioral anomalies have been shown to affect economic decisionmaking in a variety of other contexts and are being increasingly cited as an explanation for the gap. The relative contributions of the various explanations for the gap differ across energy users and energy uses. This heterogeneity poses challenges for policymakers, but also could help elucidate when different policy interventions will most likely be cost-effective. If behavioral anomalies can be more cleanly linked to energy efficiency investments, then policymakers will face new challenges in performing welfare analysis of energy efficiency policies.

Key Words: energy efficiency, market failures, behavioral failures

JEL Classification Numbers: Q38, Q41

Contents

Bridging the Energy Efficiency Gap: Insights for Policy from Economic Theory and Empirical Analysis

Kenneth Gillingham and Karen Palmer*

Introduction

In recent years, U.S. energy policy discussions have focused increasingly on enhancing the efficiency with which the economy uses energy to deliver services such as transport, refrigeration, cooking, and space heating and cooling. This focus is motivated by a desire to reduce emissions of CO_2 and other pollutants, increase the security of energy supply, and reduce the need for new energy supply infrastructure, such as difficult to site power plants and transmission lines. In the absence of a federal policy to cap or tax CO_2 emissions, promoting low or zero emitting energy technologies through a mixture of standards and incentives has become the main policy mechanism for addressing concerns about global warming. More efficient end-use technologies are an important component of a clean energy technology portfolio. In the United States, energy security implications are primarily related to improvements in the efficiency of the vehicle fleet, with some implications for home heating and industrial uses.[1]

The potential to reduce energy consumption and CO_2 emissions through investments in energy efficient equipment and appliances has been highlighted in several studies by McKinsey and Company (Creyts et al. 2007; Granade et al. 2009; McKinsey & Company 2009), the latest of which suggests that 835 megatons of carbon dioxide equivalent can be reduced in 2030 at a net savings of over $45 billion 2005 dollars. These studies and others (Chandler and Brown 2009; EPRI 2009; Meier, Wright, and Rosenfeld 1983; National Academy of Sciences 2009; Stoft 1995) suggest that the present discounted value of future energy savings greatly exceeds the upfront cost of energy efficient products. The ideas underlying these studies even play a role in policy: the Draft Regulatory Impact Analysis of the tightened new light duty vehicle greenhouse gas (i.e., fuel economy) standards similarly finds that the present discounted value of fuel

*Gillingham, Yale University; Palmer, Resources for the Future, palmer@rff.org.

We would like to thank Hunt Allcott, David Austin, Tim Brennan, Gloria Helfand, Hill Huntington, Kerry Smith, and two anonymous reviewers for their useful comments on an earlier draft. All errors remain the responsibility of the authors.

[1] Oil is responsible for less than 3 percent of electricity production, and less than 10 percent of homes currently heat with fuel oil (EIA 2011).

savings from the policy exceeds its initial costs, which suggests that improvements in the fuel efficiency of the vehicle fleet can reduce CO_2 emissions at no cost (NHTSA 2011).

The failure of consumers to make seemingly positive net present value energy saving investments has been the subject of an economic literature dating back to Hausman (1979), which suggests that individuals behave as if they heavily discount future energy savings when selecting the energy efficiency of a purchased durable good (Train 1985). More recently, studies of vehicle purchasing behavior find that individuals behave as if they "undervalue" future fuel savings (Allcott and Wozny 2012) or the product attribute of energy efficiency (Helfand and Wolverton 2011). All of these studies suggest that there is something about how individuals make decisions about energy efficiency that leads to a slower penetration of energy efficient products into the market than *might be expected* if consumers made all positive net present value investments. This phenomenon has become known as the *energy efficiency gap* or *energy efficiency paradox*. In some cases the energy efficiency gap is defined even more broadly to describe the slower than socially optimal rate of diffusion of energy efficient products (Jaffe and Stavins 1994).

The very existence of the energy efficiency gap has been met with skepticism from economists, and the use of the McKinsey-style cost curves for defining cost-effective energy efficiency potential has been met with even more skepticism. The critical issue comes down to whether individual decisionmaking is modeled correctly and whether all relevant costs are accounted for.

Economists have long recognized that market failures, including environmental externalities, inefficient pricing of energy, lack of information, and agency issues, can lead to inefficiently low levels of investment in energy efficiency. Recently, some economists have proposed that systematic behavioral biases in consumer decisionmaking may explain the apparent efficiency gap (Allcott, Mullainathan, and Taubinsky 2012; Tietenberg 2009). Proponents of this view posit that there may be a role for economic efficiency-improving policy to promote energy efficiency that is not motivated by traditional market failures.

In this article, we review the different explanations for the perceived efficiency gap based on both neoclassical economics and the latest advances in the behavioral economics literature. The existing literature guides our review: the focus is predominantly on consumers, but evidence on firms is included where relevant.[2] Our review suggests that engineering studies do not provide a true estimate of the gap or the supply of cost-effective energy savings from energy efficiency because they typically fail to account for all costs and neglect particular types of economic behavior, such as investment under uncertainty and rebound. Nonetheless, there is empirical evidence that market failures such as asymmetric information and agency problems affect efficiency decisions and contribute to the gap. Behavioral anomalies have been shown to affect economic decisionmaking in a variety of other contexts and are being increasingly cited as an explanation for the gap. We find it plausible that behavioral anomalies influence efficiency decisions, yet there is scant empirical evidence demonstrating the extent of that influence.

If a link between behavioral anomalies and energy efficiency decisions is demonstrated, it raises fundamental questions about how to perform welfare analysis. We find recent efforts to develop a behavioral welfare economics to be an important first step toward answering these questions, but these efforts are far from ready for use in policy analysis.

The most compelling motivation for energy efficiency policy may be related to the broader issues of climate change and energy security that U.S. policymakers have had extreme difficulty tackling directly. Unaddressed externalities such as these lead to a gap between the socially optimal rate of investment in energy efficiency and that occurring in markets. Promoting energy efficiency is a second-best way to address these externalities, but it may be more feasible than taxes on emissions or energy use. How effective and cost-effective energy efficiency policies will be at reducing these externalities depends on the size and sources of the gap, which are explored in the next three sections and followed by a review of what we know about the effectiveness and cost-effectiveness of existing policies in this arena.

Why the Efficiency Gap May Be Small

Despite over 30 years of inquiry into the size of the gap, the answer remains elusive. Many economists believe that consumer choices reveal more about the economics of energy efficiency improvements than do engineering calculations. If those who estimate energy savings potential from seemingly cost-effective investments in efficiency neglect some costs or inappropriately model the consumer's problem, then their assessment of what is optimal from the

[2] Firms may differ from consumers to the extent that they employ professional energy managers. However, such focus on energy management is not universal among businesses; thus, firms may be subject to many of the same issues as consumers in their efficiency investment practices.

consumer perspective is incorrect. In this case, the net benefits from efficiency investments are overstated, and the gap may be much smaller than estimated, or there may be no gap at all (Metcalf and Hassett 1999; Smith and Moore 2010). The explanations for why this engineering-based approach may overstate net benefits include hidden costs, heterogeneity in consumers, and failure to account for risk and uncertainty in the decision process.

Hidden costs may be as simple as the administrative costs of an energy efficiency program or the time costs to find or install a more energy efficient product that is equally reliable as the known product. They also include the opportunity cost of the services or alternative investments that consumers forgo to make the investment in energy efficiency. One potentially important opportunity cost is a decrease in the quality of the energy service provided. For example, more energy efficient lighting may come at the cost of less pleasing or lower quality light. In vehicles, higher fuel economy may be bundled with less desirable attributes such as small size or slower acceleration. When firms are choosing whether to make energy efficiency investments, they may be diverting scarce managerial attention from other projects that may be more essential to the firm. Differences in quality and other opportunity costs are difficult to measure and must be evaluated on a case-by-case basis. Anderson and Newell (2004) examine free energy audits for manufacturing plants and find that roughly half of the projects recommended by auditors were not adopted despite extremely short payback periods. When asked, plant managers responded that as much as 93 percent of the projects were rejected for economic reasons, many of which relate to high opportunity costs.

Heterogeneity in consumers may also help to explain the slow diffusion of energy efficient products. Products that appear financially attractive for the average consumer may not be attractive for many consumers, based on differences in preferences, expected use of the product, and the cost of borrowing (Allcott and Greenstone 2012; Golove and Eto 1996). For example, consumers purchasing an air conditioner for a summer home that is only used for a few weeks during air conditioning season may be better off not purchasing a more expensive energy efficient air conditioner, but this distinction is lost when the average energy savings is applied to the entire population of potential appliance purchasers. Bento, Li, and Roth (2012) also point to the possibility that heterogeneity in preferences may bias empirical studies toward finding that consumers undervalue savings if such heterogeneity leads consumers with higher preferences for future fuel savings to sort into more fuel-efficient products.

Investing in energy efficiency may be risky due to the irreversibility of the investment and fluctuating energy prices. If energy prices fall, then the return on the investment falls as wellHassett and Metcalf (1993) and Metcalf (1994) develop a model of consumer decisionmaking under uncertainty to show that including uncertainty increases the rate of return needed to make a yes/no energy efficiency investment attractive by four or five times. However, Sanstad, Blumstein, and Stoft (1995) point out that this option value may not be sufficient to explain observed high implicit discount rates in many settings. Baker (2012) further tempers the Hassett and Metcalf result by showing that it does not apply when there are multiple choices with different efficiencies. Nevertheless, Anderson and Newell (2004) find that risk is a common explanation for firms' rejecting energy audit recommendations.[3] Uncertainty about product performance may similarly slow diffusion. In the presence of such uncertainties, consumers and firms may be better off delaying the investment until the uncertainties are resolved (Dixit and Pindyck 1994).

In addition to understating costs, engineering calculations can be prone to overstating the energy savings from particular investments. In some cases this can arise from failure to account for interactions between different investments such as efficient lighting and cooling (Huntington 2011). Engineering simulations may also tend to assume perfect installation and maintenance of the energy efficiency investments, thereby overstating the projected energy savings. Dubin, Meidema, and Chandran (1986) find that engineering simulations of the energy savings from residential energy efficiency improvements overstated the returns by 8 to 13 percent in a randomized controlled experiment in Florida.

Interestingly, engineering approaches may also underestimate the size of the gap by assuming a constant energy service demand before and after the efficiency investment. To the extent that consumers use more energy services due to the lower cost of usage, a response known as the *rebound effect*, consumer choice theory suggests that welfare increases. Thus, the engineering estimates would understate the rate of economically efficient technology diffusion.[4] Conversely, with an unaccounted-for rebound effect, estimates of cost-effective energy savings are likely to be biased upward.

Lastly, economists have long noted that, to the extent environmental and national security externalities are not already addressed by policy, they may lead to a divergence between the market rate of adoption of energy efficient products and the socially efficient rate of adoption (Convery 2011; Jaffe and Stavins 1994; Levine et al. 1995). However, benefits from reducing

[3] Risk aversion and inertia (Stern and Aronson 1984) may be difficult to disentangle.

[4] We thank Tim Brennan for pointing this out to us.

externalities are often treated separately in energy efficiency analyses and not considered part of the energy efficiency gap.

Market Failure Explanations for the Gap

Imperfect Information for Consumers

If consumers have imperfect information about the energy savings from investing in more energy efficient products, then they may be disinclined to invest in them. In some cases, sellers may have better information than buyers about the energy efficiency of a product and may be unable to credibly convey that information to the market, leading to a market failure from asymmetric information. Imperfect or asymmetric information may exacerbate the apparent risk of energy efficiency investments and may even help explain why Anderson and Newell (2004) find that project risk was an important rationale for firms not adopting recommended energy efficiency measures from energy audits.

Principal–Agent Issues

Principal–agent problems arise when one party makes a decision relating to energy use, while another party pays or benefits from this decision. For example, a landlord may pay for heating, while the tenant chooses how much energy to use. Or a landlord may choose the energy efficiency of the dwelling, while the tenant pays for energy use and imperfectly observes this attribute when the rental contract is executed. There is empirical evidence suggesting that these situations may lead to increased energy use or reduced energy efficiency in the residential setting (Davis 2012; Gillingham, Harding, and Rapson 2012), but the magnitude of the energy losses from such split incentives is relatively small in the cases examined. However, principal–agent problems may also apply to organizations, such as when different individuals are responsible for energy bills and capital accounts. Principal–agent issues in organizations are often discussed (Tietenberg 2009), but their effects have not been quantified.

Credit Constraints

Credit constraints, also known as liquidity constraints, could also be an explanation for the energy efficiency gap (Golove and Eto 1996). Limited access to credit may prevent some consumers from purchasing a more energy efficient product or from making efficiency enhancing improvements to their homes due to the high upfront cost. Limited access to credit may be a result of credit rationing, which can occur when asymmetric information on credit risk prevents lenders from distinguishing borrowers with good credit risks from those with bad. In the energy efficiency context, lack of information on the part of the lender about the payoff from efficiency investments may contribute to credit rationing. Investments with particularly high energy savings payoffs, which could reduce the risk of default, may not be made because lenders cannot distinguish them from investments with low payoffs. Credit rationing may be particularly acute in the energy efficiency context if borrowers with high energy savings payoffs, and correspondingly low risk of default, also happen to have poor credit (Palmer, Walls, and Gerarden 2012).

Learning by Using

The process of using a new energy efficient technology may produce knowledge about how best to use the product, and this knowledge may spill over to others in the future. If this is the case, initial users will have a less than socially optimal incentive to adopt the energy efficient product. Mulder, DeGroot, and Wofkes (2003) present a simulation model that represents such effects in firm decisions regarding replacement of seemingly inferior technologies, including energy inefficient ones. However, we are not aware of any empirical evidence on the learning-by-using phenomenon for energy efficient technologies.

Regulatory Failures

Economic regulation of electricity markets results in prices that differ from marginal costs, and that difference can distort incentives for investment in energy efficiency. If regulated prices fall below marginal cost, then regulation contributes to the efficiency gap, although the opposite can also be true. This pricing distortion has a temporal dimension as consumers generally face time-invariant electricity prices and thus fail to see changes in electricity costs between expensive peak periods and lower cost off-peak periods when price tends to be above marginal cost (Brennan 2011). Overall, since electricity prices exceed efficient levels for most of the day, more efficient pricing of electricity may actually result in lower demand for energy efficiency. On net, it is unlikely that regulatory failures are an important explanation for the gap.

Behavioral Anomalies Explaining the Gap

Beginning with the work of Kahneman and Tversky in the 1970s, the field of psychology and economics (i.e., behavioral economics) has documented numerous cases in which observed consumer behavior differs from the standard assumptions of neoclassical economics: consumers behave as if they maximize a utility function, use all of the information available, and process this information appropriately. The idea that behavioral anomalies may be contributing to the energy efficiency gap has recently been widely discussed in both the academic literature and in the policy realm (Gillingham, Newell, and Palmer 2009; Helfand and Wolverton 2011; Shogren and Taylor 2008; Tietenberg 2009). In order to help explain the gap and provide rationale for policy intervention, these deviations from the standard assumptions must be *systematically* biased toward increasing purchases of less energy efficient products.

Systematic biases in intertemporal decisions have been described by both economists and psychologists as creating a difference between *decision utility*, which is the utility consumers maximize at the time of the choice, and *experienced utility*, which is the hedonic utility consumers later experience resulting from the prior decision (Kahneman 1994; Kahneman, Wakker, and Sarin 1997). A burgeoning literature in neuroeconomics is attempting to understand the neural pathways that control how consumers make decisions and receive experienced utility from those decisions (Camerer, Loewenstein, and Prelec 2005; Fehr and Rangel 2011). Our online Appendix A summarizes some of this recent evidence. What is the nature of these behavioral anomalies that might lead to a difference between decision utility and experienced utility? In the most general sense, behavioral economists have classified these deviations from the standard economic model into three categories: (1) nonstandard preferences, (2) nonstandard beliefs, and (3) nonstandard decisionmaking (DellaVigna 2009).[5]

Nonstandard Preferences

DellaVigna (2009) classifies nonstandard preferences as self-control problems, reference dependence, and social preference. The first two are relevant to the energy efficiency gap. Self-control problems refer to situations where consumers appear to have time-inconsistent preferences. In other words, consumers appear to take a long-term view for decisions about outcomes in the distant future, but as the future nears, discounting becomes steep. These decisions may be about unfulfilled plans or commitments to make good investments such as exercising more often, stopping smoking, eating healthier foods, or, as suggested by Tvetanov and Segerson (2011), investing in more energy efficient products. These time-inconsistent preferences are often formally represented by quasi-hyperbolic or (β, δ) preferences (Laibson

[5] Another classification of behavioral deviations is prospect theory, heuristic decisionmaking, and bounded rationality (Gillingham, Newell, and Palmer 2009), while another general classification is bounded rationality, bounded willpower, and bounded self-interest (Mullainathan and Thaler 2001).

1997; O'Donoghue and Rabin 1999).[6] Another formal model of self-control problems is the model of Gul and Pesendorfer (2001), an axiomatic approach that emphasizes preferences over sets of alternatives. Tvetanov and Segerson (2011) adopt the Gul and Pesendorfer self-control framework to explain the energy efficiency gap. However, there is no empirical evidence that self-control problems cause consumers to undervalue energy efficiency.

If consumers have reference dependent preferences, then in decisionmaking under uncertainty, the utility from any payoff depends on what it is in reference to. For example, there is empirical evidence that in many cases consumers exhibit loss aversion, so that a relative loss leads to a much larger decline in utility than the increase in utility from an equivalent relative gain (Tversky and Kahneman 1981).[7] Greene, German, and Delucchi (2009) propose that loss aversion can help explain the energy efficiency gap in the context of vehicles. Consumers who are deciding whether to purchase an energy-efficient vehicle are likely to be uncertain about future fuel prices, the actual energy efficiency improvement, and how much the vehicle will be driven. Thus, if consumers are loss averse, the few negative states of the world that could occur would be heavily weighted so that the energy efficient vehicle may not be purchased, even if it would have positive net benefits in most states of the world. However, Greene, German, and Delucchi (2009) do not provide empirical evidence of loss aversion to support their model.

Nonstandard Beliefs

Nonstandard beliefs are systematically incorrect beliefs about the future (DellaVigna 2009). For example, Allcott (2012) uses survey data to elicit consumer beliefs about future fuel savings from a vehicle with higher fuel economy, positing that there may be a systematic bias contributing to an undervaluation of fuel economy. Allcott finds that while consumer beliefs about future fuel savings (holding driving behavior constant) do not match the known true values, the results are inconclusive as to whether there is a systematic bias in the beliefs.

---

[6] Formally, quasi-hyperbolic or (β, δ) preferences model the presented discounted utility at time t, U_t, as the following function of the per-period utility u_t: $U_t = u_t + \beta\delta u_{t+1} + \beta\delta^2 u_{t+2} + \cdots$. In this formulation, δ is the standard discount factor, $\beta \leq 1$ captures self-control problems, while $\beta = 1$ implies the standard model of discounting.

[7] Gal (2006) suggests that inertia may be an equally valid explanation for many phenomena attributable to loss aversion.

Nonstandard Decisionmaking

Nonstandard decisionmaking has received the most interest in the academic literature, with studies relating to a variety of intertemporal decision settings. The three forms of nonstandard decisionmaking relevant to the energy efficiency gap are limited attention, framing, and suboptimal heuristics used for choices out of menus sets.

The idea that limited attention causes consumers to systematically underweight information lies at the heart of many of the arguments that behavioral anomalies can explain the energy efficiency gap. Starting with Simon (1955), economists have proposed models of bounded rationality, whereby consumers simplify complex decisions by processing only a subset of the available information. In the laboratory, individuals selectively ignore messages when the experimenter asks them to listen to another message (Broadbent 1958). In the field, consumers appear to be less attentive to certain attributes of products or prices that are less salient or obvious. For example, Chetty, Looney, and Kroft (2009) present evidence that sales taxes taken at the register are less salient than taxes added to the list price. Hossain and Morgan (2006) provide evidence that shipping costs are less salient if they are added at the end of the transaction than if they are included in the initial price. In all of these cases, there appears to be a systematic bias leading to some information effectively being ignored.

Limited attention may lead consumers to systematically misestimate the future fuel savings from a more energy efficient product if consumers tend to make a low guess of future fuel savings. While we might expect consumers to put more effort into estimating future fuel savings for large purchases, there is some evidence that simple decisionmaking processes apply in this context as well. For example, Turrentine and Kurani (2007) perform structured interviews of recent car buyers and conclude that nearly all consider future fuel savings in a very simple way that does not resemble calculating the present discounted value of future fuel costs. Some economists have argued that inattention to future fuel costs may lead to a systematic undervaluation of these costs in the context of vehicle purchases (Allcott, Mullainathan, and Taubinsky 2012), but this has yet to be demonstrated empirically.

The framing of choices has been shown to be important in a variety of complex decision settings. Bernatzi and Thaler (2002) and Duflo et al. (2006) show that presentation format can substantially affect choices by focusing attention on different subsets of the information presented. In the context of energy efficiency, government regulators have made an effort to carefully design the mandatory fuel economy labels to best present the information to address any possible behavioral anomalies in consumer information processing (EPA 2010).

Suboptimal heuristics used for choices out of (usually large) menu sets are ways for consumers to simplify the decisionmaking process. The most relevant for the energy efficiency gap are a preference for the familiar and a preference for the salient. Investors tend to underdiversify by investing in familiar companies in their state (Huberman 2001), and, in the choice of candidates on a ballot, the first politician on the list tends to stand out and receive a boost in votes (Ho and Imai 2008). When consumers are making a choice about a good from a large choice set that consists of many attributes—such as a vehicle—it is plausible that heuristics play a major role in the decision process. Turrentine and Kurani (2007) allude to this, but we are not aware of any empirical evidence on the use of heuristics, leaving this an area ripe for future research.

Heuristics as a Common Theme

While the anomalies identified above have clear differences, it may be helpful to think of many of them as the ramifications of consumers facing cognitive constraints and using potentially suboptimal heuristics to help make decisions. For example, behavior indicative of quasi-hyperbolic discounting may be the result of individuals using heuristics that involve focusing on upfront costs to make decisions. Even behavior consistent with loss aversion may come about as a result of a (possibly subconscious) heuristic to help ease the cognitive burden of decisionmaking under uncertainty.

Understanding the sources of behavioral anomalies is perhaps more important than being able to categorize these anomalies. Neuroeconomics may eventually help us understand how and why we see behavioral anomalies and when they are most likely to apply to energy efficiency decisions. It may elucidate the cognitive processes that lead to undervaluation of future fuel savings and clarify whether there is a difference between decision utility and experienced utility in common energy efficiency decisions. At this point in time, neuroeconomists have not yet begun to tackle the mental processes involved in complicated energy efficiency investment decisions. Some critics have also suggested that neuroeconomists have been too quick to draw conclusions based on limited evidence from simple experimental settings (Gul and Pesendorfer 2008; Rubinstein 2008). The nature of behavioral anomalies, and whether they truly come about due to a difference between decision and experienced utility, is critically important for welfare analysis of policies to address these anomalies in the energy efficiency realm, a subject to which we now turn.

Behavioral Anomalies and Welfare Analysis

Behavioral anomalies complicate economic welfare analysis of policies, including policies to promote energy efficiency. Standard welfare economics assumes that consumers make choices that maximize utility, given available options and constraints (e.g., budget constraints). With data on past consumption choices, the parameters of the utility function can be identified, based on the theory of revealed preference. When utility functions are calibrated to preferences that consumers reveal through their choices, the resulting model can form the basis for welfare calculations of the benefits and costs of policies (Gul and Pesendorfer 2008; Houthakker 1950; Samuelson 1938, 1948).

Two of the main underpinnings of this theory and practice are the weak axiom of revealed preference and the generalized axiom of revealed preference, both of which speak to the consistency of choices over bundles of goods. Revealed preference theory also assumes that consumer preferences are stable over time, implying that the decision utility is the same as the experienced utility. Furthermore, it assumes that consumers have full information about all consumption opportunities and that preferences do not depend on anything other than the attributes of the items in the choice set and thus are unaffected by the framing of the available choice set.

However, if behavioral anomalies lead to biased consumer choices, then it is not clear whether observed choices can be used to infer preferences. Thus the traditional approaches to welfare analysis may not provide sound estimates of the benefits and costs of government actions. If consumers receive a much lower experienced utility than decision utility from a consumption choice, should the government take a paternalistic stance and induce consumers to make the choice that leads to the higher experienced utility? If economists change the way policy analysis is conducted, what do behavioral anomalies mean for energy efficiency policy?

Several authors suggest that policymakers take a perspective that has come to be known as *libertarian paternalism* (Bernheim and Rangel 2004, 2007; Kling, Congdon, and Mullainathan 2011; Thaler and Sunstein 2003, 2008). They argue that given the influence of framing of choices on consumer behavior, one approach to policy would be for the government to allow as much freedom as possible in individual decisionmaking but establish conditions that lead to "ex post good decisions." A hallmark of this approach is simply to change the choice setting but still allow all options to be available. These minor policies to change the choice setting have been called *nudges* (Thaler and Sunstein 2008). Making an energy efficient investment a default option in a choice setting is one example of a nudge. The difficulty with this approach lies in determining what constitutes an ex post good decision. How does the policymaker know what decision is best?

Bernheim and Rangel (2007, 2009) attempt to develop a more rigorous foundation for *behavioral welfare economics* that could help answer this question. They argue for combining information on choices with information about particular attributes of the choice situations, so-called *ancillary conditions*, which are any factors that affect the individual's choices but that are not relevant for what a social planner would choose. Ancillary conditions include contextual factors such as when decisions are made, how certain options are labeled, and which option is the default option. Information about ancillary conditions can then be used to extract consistent preferences from observed behavior and measure unambiguous improvements in welfare.

Despite being widely cited, this behavioral welfare economics framework is difficult to operationalize. One must have sufficient observations of choices across different realizations of the ancillary conditions in order to separate out their effects from those of preferences on consumer choices. Yet we typically only observe choices once and thus do not have sufficient information to discern the effects of ancillary conditions (Smith and Moore 2010). The context of energy efficiency investments is no exception.

Sugden (2005, 2009) proposes a different approach. This approach involves simulating perfectly competitive markets and basing welfare calculations for policies on the outcomes in the simulated markets. He contends that this approach is particularly useful in the presence of behavioral anomalies because the surplus maximizing properties of competitive markets do not depend on the rationality of individual preferences and merely require that consumers are sensitive to prices. He further proposes implementing this framework by using estimates of the price response for goods traded in the market with estimates from hedonic analyses of the sensitivity of market prices to non-market conditions. However, Smith and Moore (2010) point out that simulating markets is likely to be impractical in many situations. Energy efficiency is likely among them.

In a working paper, Green and Hojman (2007) propose a third framework. The framework characterizes choices as the result of a compromise among simultaneously held and possibly conflicting sets of preferences. These preferences are aggregated into a decision based on some rule, and this rule can be determined as the one that can explain all observed outcomes for a given choice set. The development of the framework is based on social choice theory, where the aggregation of individual preferences through the political process inevitably results in inconsistencies. While this approach has some intuitive appeal, it is likely even more difficult to operationalize. In the context of energy efficiency, the data requirements would be onerous.

Other economists have viewed the efforts at developing a theory of behavioral welfare economics skeptically. Gul and Pesendorfer (2008) view it as a misguided exercise and caution that using experienced utility for welfare analysis is a type of "social activism" that confounds a philosophical stance with an economic analysis. Smith and Moore (2010) posit that the behavioral anomalies can be thought of as cognitive constraints added to the consumer's utility maximization problem. So when consumers appear to be inattentive or otherwise use heuristics for making decisions, they are just optimizing under these constraints. Smith and Moore see consumers as rational, capable of optimizing and processing information effectively, and offer this as a reason for continuing to rely on traditional welfare analysis.

Despite being at the research frontier, behavioral economics considerations already underpin current regulatory analyses in the energy efficiency arena, such as those for CAFE standards (NHTSA 2011). In this spirit, several recent papers perform simulation analyses in order to provide insight into how cost–benefit analyses of energy efficiency policies would change if behavioral failures provide motivation for policy (Allcott, Mullainathan, and Taubinsky 2012; Krupnick et al. 2010; Parry, Evans, and Oates 2010). These studies find that energy efficiency standards can be justified on economic efficiency grounds if behavioral anomalies lead to a sufficiently large systematic difference between decision utility and experienced utility.

Allcott, Mullainathan, and Taubinsky (2012) point out that there is likely to be heterogeneity in how consumers misoptimize. So policymakers could design more economically efficient policies through behavioral targeting, which focuses the policies on those who systematically misoptimize to a greater degree. To create behaviorally targeted policies, policymakers must understand the extent of behavioral anomalies as well as the degree of heterogeneity. Behavioral targeting is conceptually similar to the Camerer et al. (2003) proposal for "asymmetric paternalism," i.e., crafting policies that create large benefits for those who make errors with little or no harm to those who do not.

Energy Efficiency Policy

Economists have long recognized that policies tailored in form and magnitude to address relevant market failures can improve economic efficiency. To the extent that there is a deviation between decision utility and experienced utility, policies to address behavioral anomalies in energy efficiency may also enhance economic efficiency. This section discusses three types of policies to address the energy efficiency gap and summarizes what we know about their effectiveness and cost.

Economic Incentives

The most direct approach to address environmental and energy security externalities is to increase the price of energy through taxes on emissions (Fischer and Newell 2008) and energy use (Brown and Huntington 2010). An optimal tax would make the private cost to consumers equal to the social cost. A cap-and-trade system could serve the same function. These policies would unequivocally raise the price of energy, making energy efficient products more financially attractive.

Political challenges to taxing or capping emissions, along with the desire to address behavioral anomalies in efficiency markets, have led to greater reliance on subsidies to encourage investment in more energy efficient equipment. Subsidies may take the form of rebates, tax incentives, and low cost loans for purchase of energy efficient durables. Financial incentives in the form of prizes are also used to encourage the development of energy efficient technologies (Gillingham, Newell, and Palmer 2006) and to encourage reduced electricity consumption during critical peak periods (Faruqui and Sergici 2009).

Debate continues about whether subsidies for energy efficient products improve welfare and how much they reduce energy use. Subsidies require a funding source, which often is from a distortionary tax, implying a loss in economic efficiency. Subsidies can also lead to the rebound effect, which reduces energy savings.

Further complicating evaluation of subsidy programs are inframarginal consumers, often referred to as *free riders*, who would have bought the efficient appliance without the program but who avail themselves of the subsidy (Joskow and Marron 1992). Working in the opposite direction are consumers, sometimes called *free drivers*, who purchase the efficient product because their awareness was raised by the existence of the rebate (Blumstein and Harris 1993; Eto et al. 1996; Geller and Attali 2005).

An extensive literature looks at the effectiveness and cost-effectiveness of utility energy efficiency programs, which typically combine information provision with rebates and other financial incentives. While most of this literature on cost-effectiveness takes an ex ante perspective, a growing number of studies analyze this issue empirically using retrospective data.[8] These studies (Arimura et al. 2012; Auffhammer, Blumstein, and Fowlie 2008; Loughran and Kulick 2004) all tend to find that the cost per kilowatt hour saved is greater than utilities and other advocates typically estimate. However, Auffhammer et al. and Arimura et al. find that the differences between their estimates of cost effectiveness and those reported by utilities are not statistically significant. In a study of programs in Canada, Rivers and Jaccard (2011) find that energy efficiency spending has no effect on electricity demand growth.

Subsidies can also be combined with taxes on inefficient products. Such a feebate policy can be made revenue-neutral by choosing a reference level of efficiency such that purchasers of a product with lower efficiency must pay a fee while those who purchase a product with higher efficiency receive a rebate. Feebate policies have been implemented for new vehicles in Canada and France and have been discussed in the United States (Greene 2009; Greene et al. 2005; Johnson 2006). Feebates may be more politically feasible because the funding mechanism is built into the policy but are likely to be a second-best policy on economic efficiency grounds.

Information Strategies

Information strategies are intended to reduce information market failures and perhaps address behavioral issues. Examples include utilities providing technical assistance to firms and low- or no-cost energy audits to households. Several studies (e.g., Stern (1985), Stern and Aronson (1984), and Abrahamse et al. (2005)) have found that by themselves, information programs that identify energy saving investments and changes in behavior have limited effects on energy consumption. In contrast, Anderson and Newell (2004) focused on industrial energy audits and found that firms did respond to the information given in the audits, adopting roughly half of the recommendations they received.

Product labeling is another form of information provision that has been used to help consumers learn about energy use of a particular product and how it compares to other models. Federal labeling policies include the Energy Guide Labeling program for new appliances and the fuel economy labels for new cars. Recently New York City, San Francisco, and Washington, DC, have adopted public disclosure rules about energy use in commercial buildings above a

[8] Brennan (2010) looks at the economic efficiency implications of these ex ante cost effectiveness tests.

certain size threshold, and California and Washington State require disclosure of energy use for large commercial buildings upon sale.[9]

The federal government also facilitates voluntary energy efficiency through its Energy Star program, which applies to both products and buildings. Energy Star sets energy use standards for over 60 categories of products and gives the right to display the Energy Star label to those products that meet or exceed these standards. Energy Star also provides tools for evaluating and improving the energy performance of homes and commercial buildings. Several states and utilities offer incentives to households that purchase Energy Star appliances.

Some information programs leverage social norms by providing consumers with a comparison of their own energy consumption to that of their peers coupled with suggestions on ways to reduce energy use, including investing in energy efficiency. Schultz, Khazian, and Zaleski (2008) show that the use of social norms messaging, combined with energy savings tips, reduced energy consumption. Allcott (2011) finds that the social norm experiments conducted by Opower reduced energy consumption by 2 percent on average, roughly equivalent to the reduction from an 11–20 percent increase in price. Costa and Kahn (2010) look at a subset of Opower programs in Sacramento, California, and find that responses to these environmental nudges vary with political ideology. Ayres, Raseman, and Shih (2009) also find substantial consumption reducing effects, with a particularly strong effect on heavy energy consumers.

Energy Efficiency Standards

Energy efficiency standards require new appliances and other energy using products to meet a minimum level of energy efficiency in order to be offered in the market. Standards may help to address a variety of market failures, including principal–agent problems, information market failures and behavioral issues. However, they are a blunt instrument, and economists have been critical of their use (Hausman and Joskow 1982). Mandating efficiency through minimum standards raises concerns about the accuracy of the engineering calculations used to design the standard and the rebound effect. Moreover, when there is heterogeneity in consumer needs for energy services, a single standard would not be optimal for everyone.

[9] Information about disclosure programs is available at http://www.energystar.gov/ia/business/government/State_Local_Govts_Leveraging_ES.pdf.

Nevertheless, energy efficiency standards tend to be one of the most politically feasible, and thus most commonly used, policy instruments to promote energy efficiency. There are national product standards for nearly all major appliances, and some states have even stricter standards for some appliances. CAFE standards impose a minimum fleet-wide average fuel economy for new vehicles and building energy codes place minimum standards on the efficiency of newly constructed (and in some cases retrofitted) buildings.

The empirical literature on energy efficiency product standards is remarkably thin. Estimates of the energy savings resulting from appliance standards typically are based on ex ante engineering models and do not account for effects on consumer surplus from limiting choices (Gillingham, Newell, and Palmer 2006). These ex ante studies typically fail to capture rebound in energy use, although studies suggest that these effects may be small in many contexts (Davis 2008; Dumagan and Mount 1993).

CAFE standards are one policy where a growing literature analyzes how the policy affects energy use and welfare. Most economic studies assume that the new vehicle market is undistorted in the absence of CAFE and generally find that a major tightening of CAFE standards leads to large welfare losses (Austin and Dinan 2005; Goldberg 1998; Greene 1991; Kleit 2004). Jacobsen (2011) calculates the welfare effects in both the new and used vehicle markets, as well as the gasoline market, and finds that a gasoline tax has roughly one-sixth the welfare cost of CAFE standards.

A few empirical studies explore the effects of building codes on energy consumption. In their analysis using cross-sectional data, Jaffe and Stavins (1995) find no significant effect of building codes on energy demand. Aroonruengsawat, Auffhammer, and Sanstad (2012) find that building codes decreased per capita residential electricity consumption by 3 to 5 percent, and Jacobsen and Kotchen (2012) find electricity savings of about 4 percent. Costa and Kahn (2011) find that building codes affect residential electricity consumption in California after 1983 but not before. The difference between CAFE standards and building standards may be closely related to the much longer lifespan for buildings than vehicles, since turnover is much greater for vehicles than it is for buildings.

Conclusions and Future Research

This paper reviews the current state of the literature on the energy efficiency gap, a phenomenon so difficult to explain that it has also been labeled the "energy efficiency paradox." More than 30 years of literature suggests that consumers behave as if they have high discount rates, and recent engineering studies show a vast potential for negative-cost energy efficiency investments. However, the true size of the gap remains unclear. A variety of explanations, such as hidden costs, exaggerated engineering estimates of energy savings, consumer heterogeneity, and uncertainty all suggest that measurement errors contribute to the observed gap.

Yet measurement errors alone are not the entire story. There is empirical evidence that externalities and information market failures can create a difference between the privately chosen level of energy efficiency and the socially efficient level. Evidence is growing that behavioral anomalies influence investment decisions in a variety of contexts, and such anomalies are becoming a widely cited explanation for the energy efficiency gap. Disentangling behavioral anomalies, such as inattention, from other explanations for apparent undervaluation of savings is empirically difficult in the context of energy efficiency, and inquiries are ongoing.

What is becoming increasingly clear is that the apparent energy efficiency gap has multiple explanations and the relative contributions of each differ across groups of energy users and types of energy uses. For example, price volatility differs substantially between gasoline and electricity and thus so does the option value of waiting to invest. Credit constraints are more relevant to lower-income households purchasing appliances than they are to wealthy households purchasing a new vehicle. Informational issues differ between more and less sophisticated energy consumers.

This heterogeneity in explanations poses challenges for policymakers, but also helps elucidate when different policy interventions will most likely be cost-effective. The literature is clear that targeting policies toward specific market failures will improve cost-effectiveness. If behavioral anomalies are more cleanly linked to energy efficiency investments, then the same is true for behavioral failures. However, policymakers will then face new challenges in performing welfare analysis of energy efficiency policies. When the axioms of revealed preference do not hold, traditional approaches to welfare analysis are called into question, and new methods are needed to discern optimal policies. Such approaches will have to leverage the difference between decision utility and experienced utility, perhaps measured by neuroeconomists. To date, the developing literature on behavioral welfare economics holds promise, but it is far from ready to be implemented by policymakers. In the few situations where nudges can be used to promote energy efficiency, such as Opower’s social norms messaging experiments, we see no reason not to pursue such measures.

For researchers, the heterogeneity in explanations presents both an opportunity and a challenge. The opportunity is that there is much empirical research to be done to quantify the size and nature of the efficiency gap in different contexts. The list of outstanding issues is long. More careful studies of the full costs of energy efficient investments to consumers and firms could help clarify the role of hidden costs in hindering technology adoption. Stated preference surveys or experimental approaches could be used to study the opportunity cost of amenities lost when more efficient products (such as light bulbs) are substituted for others. Better quantification of the consumer response to information could help disentangle how information processing works in energy efficiency decisions and could establish whether behavioral anomalies relevant to energy efficiency are reduced by learning.

A further challenge to researchers is that the generalizability of findings from one energy use and energy user context to other users and uses may be limited. This is exacerbated because it is often difficult to obtain the data necessary to better understand energy efficiency investment behavior and its implications for energy use. Greater cooperation between policymakers and researchers in development of policy (including randomized policy experiments), sharing of data, and ex post analysis of policy effectiveness should lead to both a better understanding of the gap and better policy in the future. Finally, research in neuroeconomics and welfare economics focused on energy efficiency could provide a framework for analyzing the economic efficiency of energy efficiency policies in the presence of behavioral anomalies.

References

Abrahamse, Wokje, Linda Steg, Charles Vlek, and Talib Rothengatter. 2005. A Review of Intervention Studies Aimed at Household Energy Consumption. *Journal of Environmental Psychology* 25:273-291.

Allcott, Hunt. 2011. Social Norms and Energy Conservation. *Journal of Public Economics* 95 (9-10):1082-1095.

———. 2012. The Welfare Effects of Misperceived Product Costs: Data and Calibrations from the Automobile Market. *NYU Working Paper*.

Allcott, Hunt, and Michael Greenstone. 2012. Is There an Energy Efficiency Gap? *Journal of Economic Perspectives* 26 (1):3-28.

Allcott, Hunt, Sendhil Mullainathan, and Dmitry Taubinsky. 2012. Externalities, Internalities, and the Targeting of Energy Policy. *American Economic Journal: Economic Policy* forthcoming.

Allcott, Hunt, and Nathan Wozny. 2012. Gasoline Prices, Fuel Economy, and the Energy Paradox. *Working Paper*.

Anderson, Soren, and Richard Newell. 2004. Information Programs for Technology Adoption: The Case of Energy-Efficiency Audits. *Resource and Energy Economics* 26 (1):27-50.

Arimura, Toshi, Richard Newell, Karen Palmer, and Shanjun Li. 2012. Cost-Effectiveness of Electricity Energy Efficiency Programs. *Energy Journal* forthcoming.

Aroonruengsawat, Anin, Maximillian Auffhammer, and Alan Sanstad. 2012. The Impact of State-Level Building Codes on Residential Energy Consumption. *Energy Journal* 33 (1).

Auffhammer, Maximillian, Carl Blumstein, and Meredith Fowlie. 2008. Demand-Side Management and Energy Efficiency Revisited. *Energy Journal* 29 (3):91-104.

Austin, David, and Terry Dinan. 2005. Clearing the air: The costs and consequences of higher CAFE standards and increased gasoline taxes. *Journal of Environmental Economics and Management* 50 (3):562-582.

Ayres, Ian, Sophie Raseman, and Alice Shih. 2009. Evidence from Two Large Field Experiments that Peer Comparison Feedback Can Reduce Electricity Usage. *NBER Working Paper 15386*.

Baker, Erin. 2012. Option Value and the Diffusion of Energy Efficient Products. *Energy Journal* 33 (4):49-59.

Bento, Antonio, Shanjun Li, and Kevin Roth. 2012. Is There an Energy Paradox in Fuel Economy? A Note on the Role of Consumer Heterogeneity and Sorting Bias. *Economics Letters* 115 (1):44-48.

Bernatzi, Shlomo, and Richard Thaler. 2002. How Much is Investor Autonomy Worth? *Journal of Finance* 57 (4):1593-1616.

Bernheim, B. Douglas, and Antonio Rangel. 2004. Addiction and Cue-Triggered Decision Processes. *American Economic Review* 94 (5):1558-1590.

———. 2007. Behavioral Public Economics: Welfare and Policy Analysis with Non-standard Decision Makers. In *Behavioral Economics and Its Applications*, edited by P. Diamond and H. Vartiainen. Princeton, NJ: Princeton University Press.

———. 2009. Beyond Revealed Preference: Choice Theoretic Foundations for Behavioral Welfare Economics. *Quarterly Journal of Economics* 124 (1):51-104.

Blumstein, Carl, and Jeffrey Harris. 1993. The Cost of Energy Efficiency. *Science* 261 (5124):970.

Brennan, Timothy. 2010. Optimal Energy Efficiency Policies and Regulatory Demand-Side Management Tests. *Energy Policy* 38 (8):3874-3885.

———. 2011. Energy Efficiency Policy: Surveying the Puzzles. In *Resources for the Future Discussion Paper 11-27*. Washington, DC: Resources for the Future.

Broadbent, Donald. 1958. *Perception and Communication*. New York, NY: Pergamon Press.

Brown, Stephen, and Hillard Huntington. 2010. Estimating U.S. Oil Security Premiums. Washington, DC: Resources for the Future.

Camerer, Colin, Samuel Issacharoff, George Loewenstein, Ted O'Donoghue, and Matthew Rabin. 2003. Regulation for Conservatives: Behavioral Economics and the Case for "Asymmetric Paternalism". *University of Pennsylvania Law Review* 151:1211-1254.

Camerer, Colin, George Loewenstein, and Drazen Prelec. 2005. Neuroeconomics: How Neuroscience Can Inform Economics. *Journal of Economic Literature* 43 (1):9-64.

Chandler, S., and M. Brown. 2009. Meta-Review of Efficiency Potential Studies and Their Implications for the South. *Georgia Tech Ivan College of Public Policy Working Paper 51*.

Chetty, Raj, Adam Looney, and Kory Kroft. 2009. Salience and Taxation: Theory and Evidence. *American Economic Review* 99 (4):1145-1177.

Convery, Frank. 2011. Reflections - Energy Efficiency Literature for Those in the Policy Process. *Review of Environmental Economics and Policy* 5 (1):172-191.

Costa, Dora, and Matthew Kahn. 2010. Energy Conservation "Nudges" and Environmentalist Ideology: Evidence from a Randomized Residential Electricity Field Experiment. *NBER Working Paper 15939*.

———. 2011. Electricity Consumption and Durable Housing: Understanding Cohort Effects. *American Economic Review Papers and Proceedings* 101 (3):88-92.

Creyts, Jon, Anton Derkach, Scott Nyquist, Ken Ostrowski, and Jack Stephenson. 2007. Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost? : McKinsey & Company.

Davis, Lucas. 2008. Durable Goods and Residential Demand for Energy and Water: Evidence from a Field Trial. *RAND Journal of Economics* 39 (2):530-546.

———. 2012. Evaluating the Slow Adoption of Energy Efficient Investments: Are Renters Less Likely to Have Energy Efficient Appliances? In *The Design and Implementation of U.S. Climate Policy*, edited by D. Fullerton and C. Wolfram. forthcoming.

DellaVigna, Stefano. 2009. Psychology and Economics: Evidence from the Field. *Journal of Economic Literature* 47 (2):315-372.

Dixit, A., and R. Pindyck. 1994. *Investment Under Uncertainty*. Princeton, NJ: Princeton University Press.

Dubin, Jeffrey, Allen Meidema, and Ram Chandran. 1986. Price Effects of Energy-Efficient Technologies: A Study of Residential Demand for Heating and Cooling. *RAND Journal of Economics* 17 (3):310-325.

Duflo, Esther, William Gale, Jeffrey Liebman, Peter Orszag, and Emmanuel Saez. 2006. Saving Incentives for Low- and Middle-Income Families: Evidence from a Field Experiment with H&R Block. *Quarterly Journal of Economics* 121 (4):1311-1346.

Dumagan, J.C., and T.D. Mount. 1993. Welfare Effects of Improving End-Use Efficiency: Theory and Application to Residential Electricity Demand. *Resource and Energy Economics* 15 (2).

EIA. 2011. Annual Energy Review 2010. Washington, DC: U.S. Department of Energy.

EPA. 2010. Environmental Protection Agency Fuel Economy Label. Washington, DC: US Environmental Protection Agency.

EPRI. 2009. Assessment of Achievable Potential from Energy Efficiency and Demand Response Programs in the US 2010-2030. Electric Power Research Institute.

Eto, Joseph, Edward Vine, Leslie Shown, Richard Sonnenblick, and Chris Payne. 1996. The Total Cost and Measured Performance of Utility Sponsored Energy-Efficiency Programs. *The Energy Journal* 17 (1):31-52.

Faruqui, Ahmad, and Sanem Sergici. 2009. Household Response to Dynamic Pricing of Electricity-A Survey of the Experimental Evidence. San Francisco, CA: Brattle Group.

Fehr, Ernst, and Antonio Rangel. 2011. Neuroeconomic Foundations of Economic Choice-Recent Advances. *Journal of Economic Perspectives* 25 (4):3-30.

Fischer, Carolyn, and Richard Newell. 2008. Environmental and Technology Policies for Climate Mitigation. *Journal of Environmental Economics and Management* 55 (2):142-162.

Gal, D. 2006. A Psychological Law of Inertia and the Illusion of Loss Aversion. *Judgement and Decision Making* 1 (1):23-32.

Geller, Howard, and Sophie Attali. 2005. The Experience with Energy Efficiency Policies and Programmes in IEA Countries: Learning from the Critics. Paris, France: International Energy Agency.

Gillingham, Kenneth, Matthew Harding, and David Rapson. 2012. Split Incentives and Household Energy Consumption. *Energy Journal* 33 (2):37-62.

Gillingham, Kenneth, Richard Newell, and Karen Palmer. 2006. Energy Efficiency Policies: A Retrospective Examination. *Annual Review of Environment and Resources* 31:161-192.

———. 2009. Energy Efficiency Economics and Policy. *Annual Review of Resource Economics* 1 (1):597-619.

Goldberg, Penny. 1998. The Effects of Corporate Average Fuel Efficiency Standards in the U.S. *Journal of Industrial Economics* 46 (1):1-33.

Golove, William, and Joseph Eto. 1996. Market Barriers to Energy Efficiency: A Critical Reappraisal of the Rationale for Public Policies to Promote Energy Efficiency. Berkeley, CA: Lawrence Berkeley National Laboratory: LBL-38059, UC-1322.

Granade, Hannah Choi, Jon Creyts, Anton Derkach, Philip Farese, Scott Nyquist, and Ken Ostrowski. 2009. Unlocking Energy Efficiency in the U.S. Economy. McKinsey & Company.

Green, Jerry, and David Hojman. 2007. Choice, Rationality and Welfare Measurement. *Harvard University Working Paper*.

Greene, David. 1991. Short-Run Pricing Strategies to Increase Corporate Average Fuel Economy. *Economic Inquiry* 29 (1):101-114.

———. 2009. Feebates, Footprints and Highway Safety. *Transportation Research D* 14 (6):375-384.

Greene, David, John German, and Mark Delucchi. 2009. Fuel Economy: The Case for Market Failure. In *Reducing Climate Impacts in the Transportation Sector*, edited by D. Sperling and J. Cannon: Springer Science.

Greene, David, Philip Patterson, Margaret Singh, and Jia Li. 2005. Feebates, Rebates and Gas-Guzzler Taxes: A Study of Incentives for Increased Fuel Economy. *Energy Policy* 33 (6):757-775.

Gul, Faruk, and Wolfgang Pesendorfer. 2001. Temptation and Self-Control. *Econometrica* 69 (6):1403-1435.

———. 2008. The Case for Mindless Economics. In *The Foundations of Positive and Normative Economics*, edited by A. Caplin and A. Shotter. Oxford, U.K.: Oxford University Press.

Hassett, Kevin A., and Gilbert E. Metcalf. 1993. Energy Conservation Investment: Do Consumers Discount the Future Correctly? *Energy Policy* 21 (6):710-716.

Hausman, Jerry. 1979. Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables. *The Bell Journal of Economics* 10 (1):33-54.

Hausman, Jerry A., and Paul L. Joskow. 1982. Evaluating the Costs and Benefits of Appliance Efficiency Standards. *American Economic Review* 72 (2):220-225.

Helfand, Gloria, and Ann Wolverton. 2011. Evaluating the Consumer Response to Fuel Economy: A Review of the Literature. *International Review of Environmental and Resource Economics* 5 (2):103-146.

Ho, Daniel, and Kosuke Imai. 2008. Estimating Causal Effects of Ballot Order from a Randomized Natural Experiment: The California Alphabet Lottery, 1978-2002. *Public Opinion Quarterly* 72 (2):216-240.

Hossain, Tanjim, and John Morgan. 2006. ...Plus Shipping and Handling: Revenue (Non) Equivalence in Field Experiments on eBay. *B.E. Journals in Economic Analysis and Policy: Advances in Economic Analysis and Policy* 6 (2):1-27.

Houthakker, H.S. 1950. Revealed Preference and the Utility Function. *Economica* 17 (66):159-174.

Huberman, Gur. 2001. Familiarity Breeds Investment. *Review of Financial Studies* 14 (3):659-680.

Jacobsen, Grant, and Matthew Kotchen. 2012. Are Building Codes Effective at Saving Energy? Evidence from Residential Billing Data in Florida. *Review of Economics and Statistics* forthcoming.

Jacobsen, Mark. 2011. Evaluating U.S. Fuel Economy Standards in a Model with Producer and Household Heterogeneity. *UC San Diego Working Paper*.

Jaffe, A., and R. Stavins. 1994. The Energy Efficiency Gap: What Does it Mean? *Energy Policy* 22 (10):804-810.

Jaffe, Adam, and Robert Stavins. 1994. The Energy Paradox and the Diffusion of Conservation Technology. *Resource and Energy Economics* 16 (2):91-122.

———. 1995. Dynamic Incentives of Environmental Regulations: The Effects of Alternative Policy Instruments on Technology Diffusion. *Journal of Environmental Economics and Management* 29 (3):S43-S63.

Johnson, Kenneth. 2006. Feebates: An Effective Regulatory Instrument for Cost-Constrained Environmental Policy. *Energy Policy* 34 (18):3965-3976.

Joskow, Paul L., and Donald B. Marron. 1992. What Does a Negawatt Really Cost? Evidence from Utility Conservation Programs. *The Energy Journal* 13 (4):41-74.

Kahneman, Daniel. 1994. New Challenges to the Rationality Assumption. *Journal of Institutional and Theoretical Economics* 150:18-36.

Kahneman, Daniel, Peter Wakker, and Rakesh Sarin. 1997. Back to Benthem? Explorations of Experienced Utility. *Quarterly Journal of Economics* 112 (2):375-406.

Kleit, Andrew. 2004. Impacts of Long-Range Increases in the Corporate Average Fuel Economy (CAFE) Standard. *Economic Inquiry* 42 (2):279-294.

Kling, Jeffrey, William Congdon, and Sendhil Mullainathan. 2011. *Policy and Choice: Public Finance Through the Lens of Behavioral Economics*. New York, NY: Brookings Institution Press.

Krupnick, Alan, Ian Parry, Margaret Walls, Tony Knowles, and Kristin Hayes. 2010. Toward a New National Energy Policy: Assessing the Options. Washington, DC: Resources for the Future.

Laibson, David. 1997. Golden Eggs and Hyperbolic Discounting. *Quarterly Journal of Economics* 112 (2):443-477.

Levine, M., J. Koomey, J. McMahon, A. Sanstad, and E. Hirst. 1995. Energy Efficiency Policy and Market Failures. *Annual Review of Energy and the Environment* 20:535-555.

Loughran, David, and Jonathan Kulick. 2004. Demand-Side Management and Energy Efficiency in the United States. *The Energy Journal* 25 (1):19-41.

McKinsey & Company. 2009. Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Curve.

Meier, Alan, Jan Wright, and A. Rosenfeld. 1983. *Supplying Energy Through Greater Efficiency*. Berkeley, CA: University of California Press.

Metcalf, Gilbert E. 1994. Economics and Rational Conservation Policy. *Energy Policy* 22 (10):819-825.

Metcalf, Gilbert E., and Kevin A. Hassett. 1999. Measuring the Energy Savings from Home Improvement Investments: Evidence from Monthly Billing Data. *Review of Economics and Statistics* 81 (3):516-528.

Mulder, Peter, Henri DeGroot, and Marjan Wofkes. 2003. Explaining the Slow Diffusion of Energy-saving Technologies: A Vintage Model with Returns to Diversity and Learning by Using. *Resource and Energy Economics* 25 (1):105-126.

Mullainathan, Sendhil, and Richard Thaler. 2001. Behavioral Economics. In *International Encyclopedia of the Social and Behavioral Sciences*, edited by N. Smelser and P. Bates: Elsevier.

National Academy of Sciences. 2009. Real Prospects for Energy Efficiency in the U.S. Washington, DC: National Academies Press.

NHTSA. 2011. Preliminary Regulatory Impact Analysis. Washington, DC: U.S. Department of Transportation National Highway Traffic Safety Administration.

O'Donoghue, Ted, and Matthew Rabin. 1999. Doing it Now or Later. *American Economic Review* 89 (1):103-124.

Palmer, Karen, Margaret Walls, and Todd Gerarden. 2012. Borrowing to Save Energy: An Assessment of Energy Efficiency Finance Programs. Washington, DC: RFF.

Parry, Ian, David Evans, and Wallace Oates. 2010. Are Energy Efficiency Standards Justified? Washington, DC: Resources for the Future.

Rivers, Nic, and Mark Jaccard. 2011. Retrospective Evaluation of Electric Utility Demand-Side Management Programs in Canada. *Energy Journal* 32 (4-5):95-118.

Rubinstein, Ariel. 2008. Comments on Neuroeconomics. *Economics and Philosophy* 24:485-494.

Samuelson, Paul. 1938. A Note on the Pure Theory of Consumer's Behavior. *Economica* 5:61-71.

———. 1948. Consumption Theory in Terms of Revealed Preference. *Economica* 15:243-253.

Sanstad, Alan, Carl Blumstein, and Steven Stoft. 1995. How High Are Option Values in Energy Efficiency Investments. *Energy Policy* 23 (9):739-743.

Schultz, Wesley, Azar Khazian, and Adam Zaleski. 2008. Using Normative Social Influence to Promote Conservation Among Hotel Guests. *Social Influence* 3 (1):4-23.

Shogren, Jason, and Laura Taylor. 2008. On Behavioral-Environmental Economics. *Review of Environmental Economics and Policy* 2 (1):26-44.

Simon, Herbert. 1955. A Behavioral Model of Rational Choice. *Quarterly Journal of Economics* 69 (1):99-118.

Smith, Kerry, and Eric Moore. 2010. Behavioral Economics and Benefit Cost Analysis. *Environmental and Resource Economics* 46 (2):217-234.

Stern, Paul, ed. 1985. *Energy Efficiency in Buildings: Behavioral Issues*. Washington, DC: National Academy Press.

Stern, Paul, and Elliot Aronson. 1984. *Energy Use: The Human Dimension*. Washington, DC: National Academy of Sciences.

Stoft, Steven. 1995. The Economics of Conserved-Energy "Supply" Curves. *Energy Journal* 16 (4):109-140.

Sugden, Robert. 2005. Coping with Preference Anomalies in Cost-benefit Analysis: A Market Simulation. *Environmental and Resource Economics* 32 (1):129-160.

———. 2009. Market Simulation and the Provision of Public Goods: A Non-Paternalistic Response to Anomalies in Environmental Evaluation. *Journal of Environmental Economics and Management* 57 (1):87-103.

Thaler, Richard, and Cass Sunstein. 2003. Libertarian Paternalism. *American Economic Review* 93 (2):175-179.

———. 2008. *Nudge: Improving Decisions About Health, Wealth, and Happiness*. New Haven, CT: Yale University Press.

Tietenberg, T. 2009. Reflections - Energy Efficiency Policy: A Pipe Dream or a Pipeline to the Future? *Review of Environmental Economics and Policy* 3 (2):304-320.

Train, Kenneth. 1985. Discount Rates in Consumers' Energy-Related Decisions: A Review of the Literature. *Energy* 10 (12):243-253.

Turrentine, Thomas, and Kenneth Kurani. 2007. Car Buyers and Fuel Economy? *Energy Policy* 35 (2):1213-1223.

Tversky, Amos, and Daniel Kahneman. 1981. The Framing of Decisions and the Psychology of Choice. *Science* 211 (4481):453-458.

Tvetanov, Tsvetan, and Kathleen Segerson. 2011. Re-Evaluating the Role of Energy Efficiency Standards: A Time-Consistent Behavioral Economics Approach. *University of Connecticut Working Paper*.

Appendix A: Relevant Evidence from Neuroeconomics

This short appendix provides a discussion of some relevant evidence from neuroeconomics that helps us to understand better the physiological nature of the behavioral anomalies.

The recent literature using brain scans focuses on very simple choices, such as whether to choose an apple or orange for dessert. Even in this simple choice setting, a consistent finding is that individuals can often make mistakes—defined as choices individuals make that do not give the largest experienced utility signal in parts of the orbitofrontal cortex and nucleus accumbens in the brain. Based on preliminary laboratory evidence, it appears that as many as 20 percent of even simple choices may be mistakes, although this percent can change with the choice setting (Frydman et al. 2011; Krajbich, Armel, and Rangel 2010). Some of this preliminary work also suggests that there are biases in how individuals allocate limited attention in making decisions, which may occur due to heuristic decisionmaking approaches.

Two additional intriguing pieces of evidence have recently appeared in the neuroscience literature. First, Bickel et al. (2011) trained an experimental group to improve their working memory and find that the subjects appear to discount the future less in a monetary choice task than the control group does. Similarly, the results in Shamosh et al. (2008) suggest that both working memory and intelligence are correlated with lower discounting in another monetary task. These results could be taken as evidence of the importance of cognitive capacity in decisionmaking. Perhaps with more free cognitive capacity, consumers use fewer heuristics in decisionmaking and are less likely to make biased decisions.

Interestingly, these pieces of evidence from the neuroeconomics literature seem consistent with evidence that some behavioral anomalies—such as loss aversion and cognitive limitations—have been shown to diminish with market experience (List 2003; Palacious-Huerta and Volij 2009). Of course, many complex economic decisions, such as purchasing a home or vehicle, are made infrequently, so there are limited opportunities for learning (DellaVigna 2009).

References

Bickel, Warren, Richard Yi, Reid Landes, Paul Hill, and Carole Baxter. 2011. Remember the Future: Working Memory Training Decreases Delay Discounting Among Stimulant Addicts. *Biological Psychiatry* 69 (3):260-265.

DellaVigna, Stefano. 2009. Psychology and Economics: Evidence from the Field. *Journal of Economic Literature* 47 (2):315-372.

Frydman, Cary, Colin Camerer, Peter Bossaerts, and Antonio Rangel. 2011. MAOA-L Carriers are Better at Making Optimal Financial Decisions Under Risk. *Proceedings of the Royal Society B* 278 (1714):2053-2059.

Krajbich, Ian, Carrie Armel, and Antonio Rangel. 2010. Visual Fixations and the Computation and Comparison of Value in Goal-Directed Choice. *Nature Neuroscience* 13 (10):1292-1298.

List, John. 2003. Does Market Experience Eliminate Market Anomalies? *Quarterly Journal of Economics* 118 (1):41-71.

Palacious-Huerta, Ignacio, and Oscar Volij. 2009. Field Centipedes. *American Economic Review* 99 (4):1619-1635.

Shamosh, N. A., C. G. Deyoung, A. E. Green, D. L. Reis, M. R. Johnson, A. R. Conway, R. W. Engle, T. S. Braver, and J. R. Gray. 2008. Individual differences in delay discounting: relation to intelligence, working memory, and anterior prefrontal cortex. *Psychological Science* 19 (9):904-11.